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(magnetic head) &lt;and&gt; (inductive element)

☐ Check to search within this result set**Results Key:****JNL** = Journal or Magazine   **CNF** = Conference   **STD** = Standard**1 Magneto-inductive element***Mohri, K.; Kawashima, K.; Kohzawa, T.; Yoshida, H.;*

Magnetics, IEEE Transactions on , Volume: 29 , Issue: 2 , Mar 1993

Pages:1245 - 1248

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Magnetics, IEEE Transactions on , Volume: 31 , Issue: 6 , Nov. 1995

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[\[Abstract\]](#)   [\[PDF Full-Text \(356 KB\)\]](#)   **IEEE JNL**
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(12) **United States Patent**  
Kitao et al.

(10) Patent No.: **US 6,198,600 B1**  
(45) Date of Patent: **Mar. 6, 2001**

(54) **THIN FILM MAGNETIC HEAD AND  
MANUFACTURING METHOD THEREOF**

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7-230615 \* 8/1995 (JP).

(75) Inventors: **Mitsuhiko Kitao; Hiroki Nakazawa;  
Kelichi Shibata; Monjiro Momoi;  
Noboru Yamanaka**, all of Tokyo (JP)

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K. Fukuda, et al. "Off-track Capability of a Pole Trimmed  
Thin Film Head," IEEE Transactions on Magnetics, vol. 30,  
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\* cited by examiner

(73) Assignee: **TDK Corporation**, Tokyo (JP)

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 0 days.

*Primary Examiner*—William Klimowicz

(74) *Attorney, Agent, or Firm*—Oblon, Spivak, McClelland,  
Maier & Neustadt, P.C.

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(30) **Foreign Application Priority Data**

Jun. 10, 1998 (JP) ..... 10-162683

(51) **Int. Cl.<sup>7</sup>** ..... **G11B 21/21; G11B 17/32;  
G11B 5/60**

(52) **U.S. Cl.** ..... **360/235.2; 360/236.5**

(58) **Field of Search** ..... **360/234.7, 234.9,  
360/235.1, 235.7, 235.8, 235.2, 236.5**

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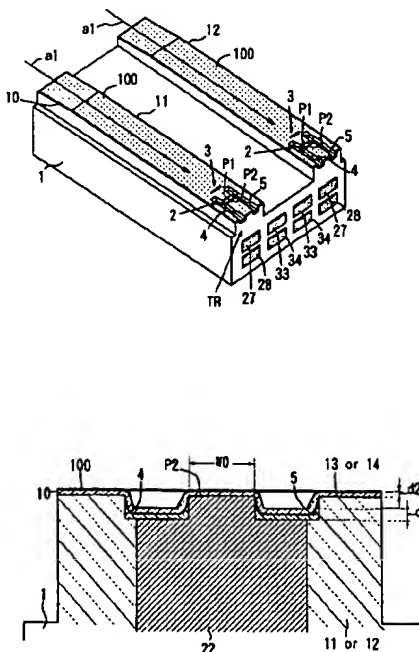
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(57) **ABSTRACT**

The present invention is directed to a thin film magnetic head and its manufacturing method. A slider 1 is provided with base body surfaces 13 and 14 at its surface facing opposite a medium. An inductive thin film magnetic transducer 2 is provided with a first pole tip P1 and a second pole tip P2 whose front ends emerge at the base body surfaces 13 and 14 and indented portions 4 and 5 provided at the base body surfaces 13 and 14. A protective film 10 covers the base body surfaces 13 and 14 and indented portions 4 and 5. The thickness of the protective film 10 at the indented portions 4 and 5 is larger than the thickness at the base body surfaces 13 and 14. The magnetic films constituting the pole tips P1 and P2 can thus be reliably protected from oxidation, corrosion and the like, while minimizing the spacing loss.

**20 Claims, 7 Drawing Sheets**



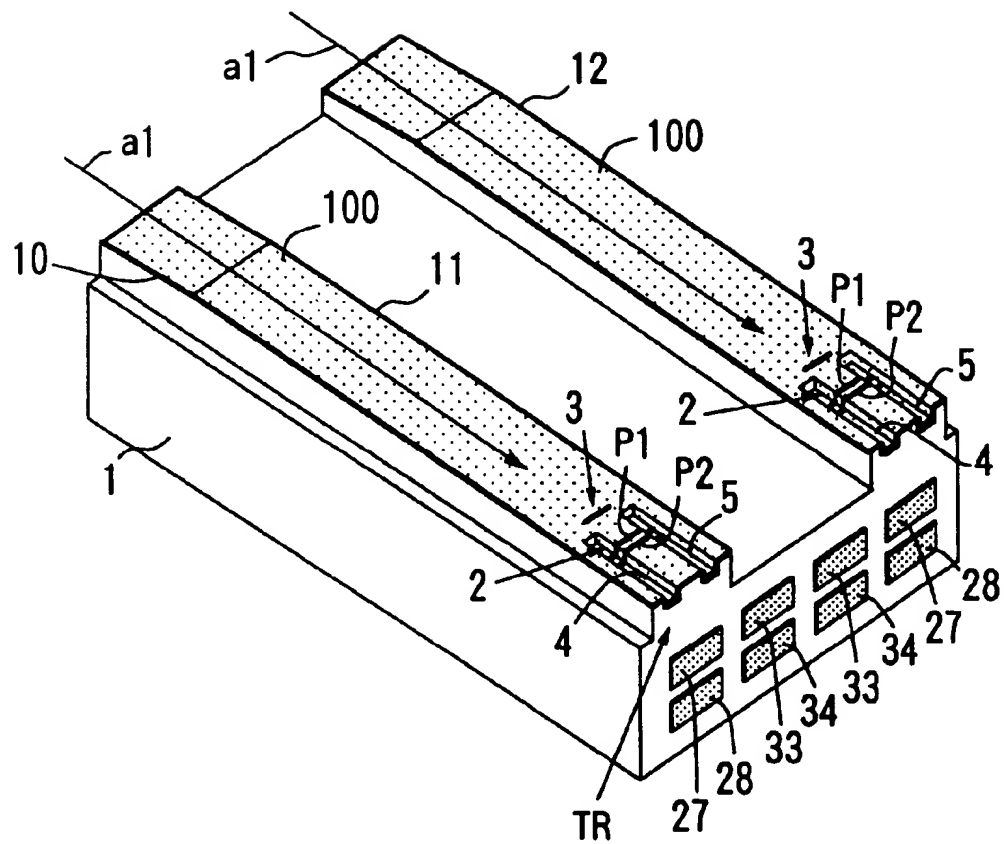


FIG. 1

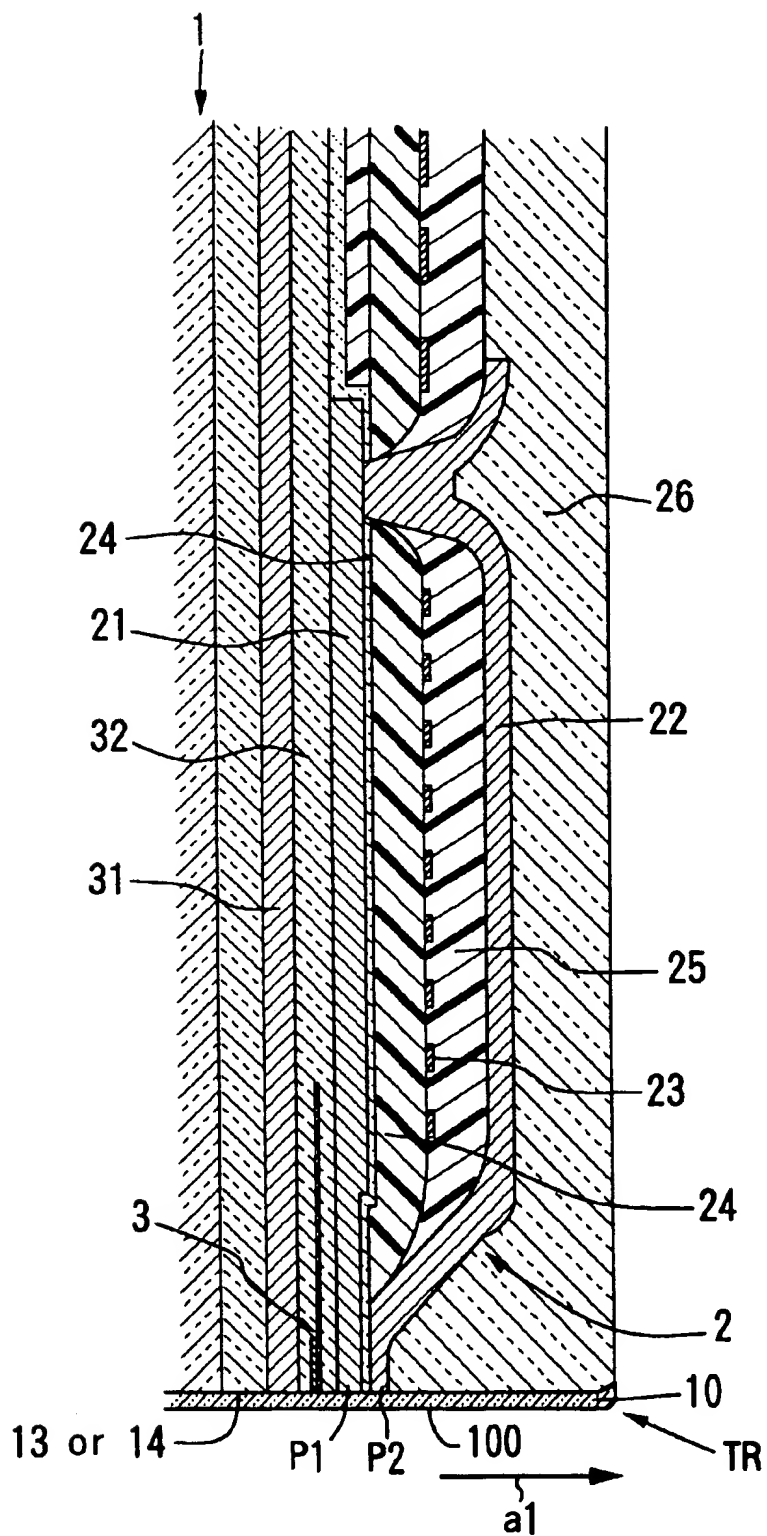


FIG. 2



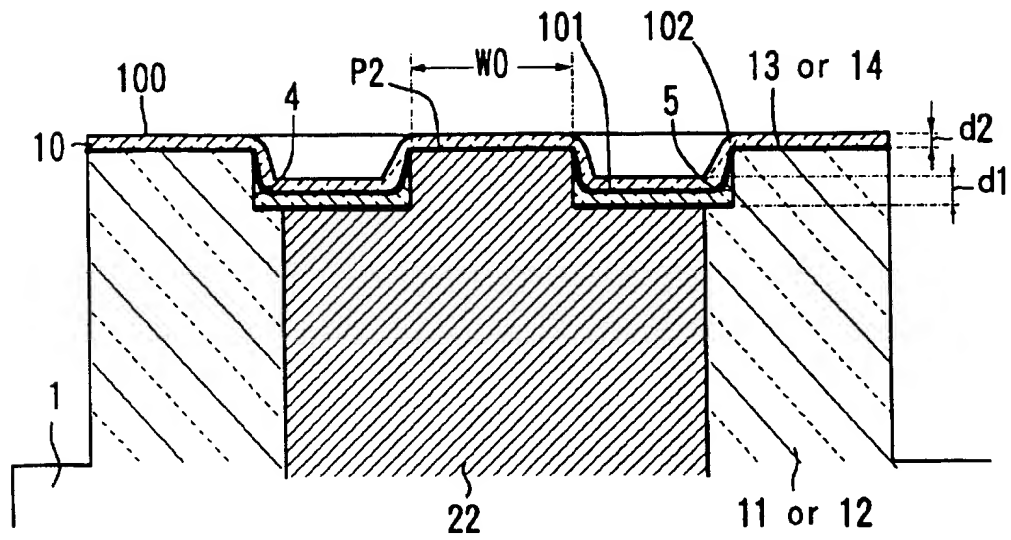


FIG. 5

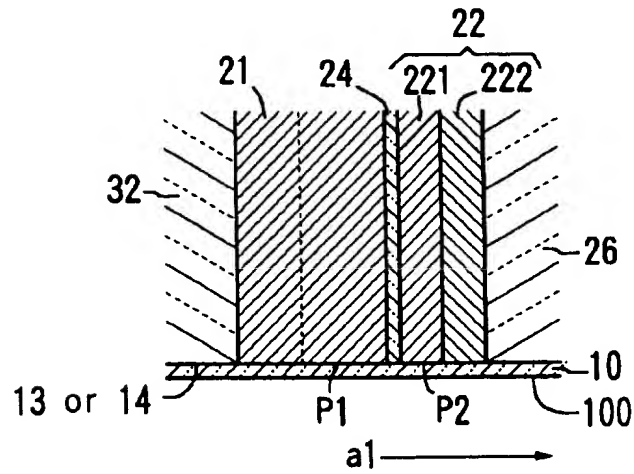


FIG. 6



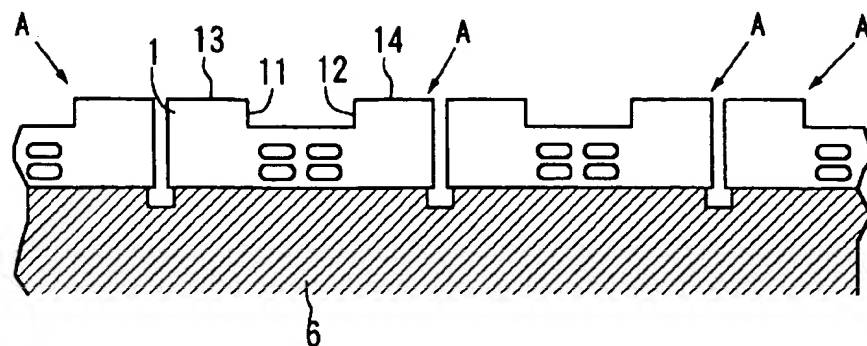


FIG. 7

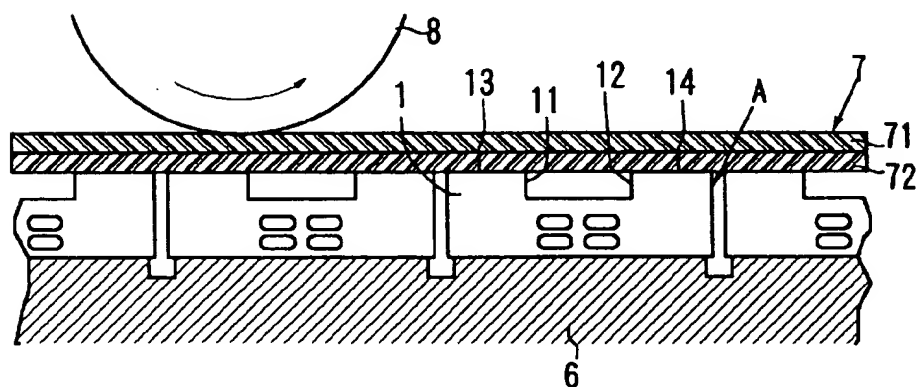


FIG. 8

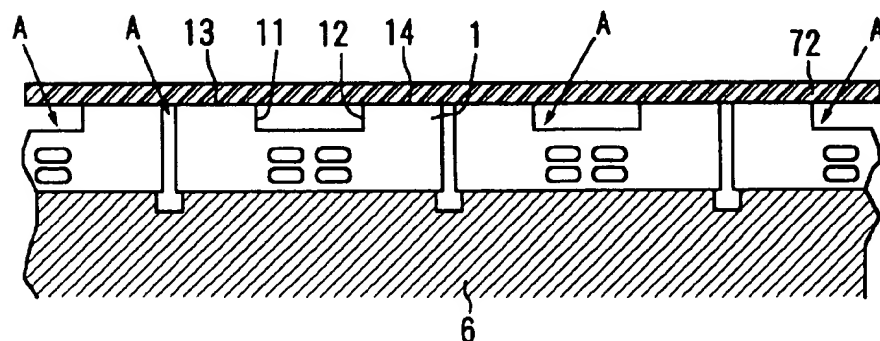


FIG. 9

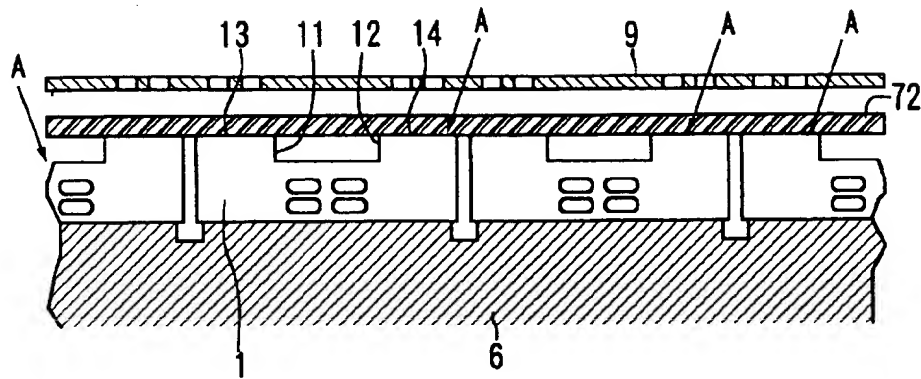


FIG. 10

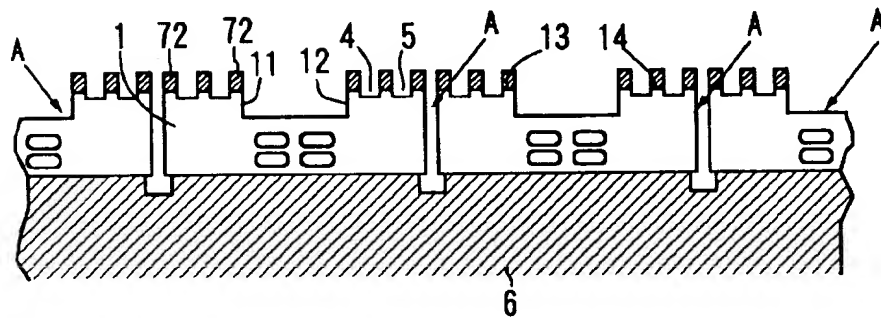


FIG. 11

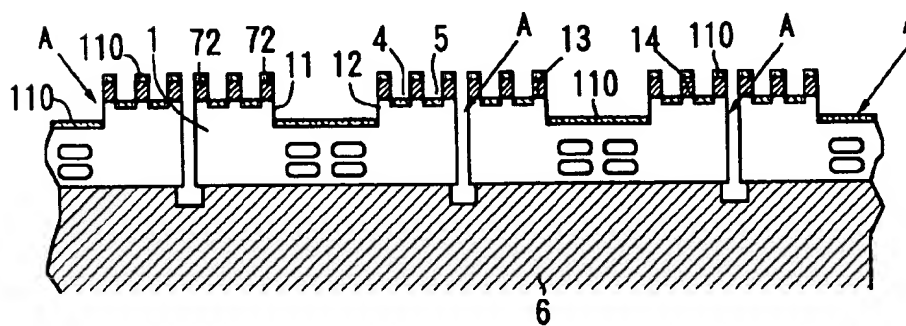


FIG. 12

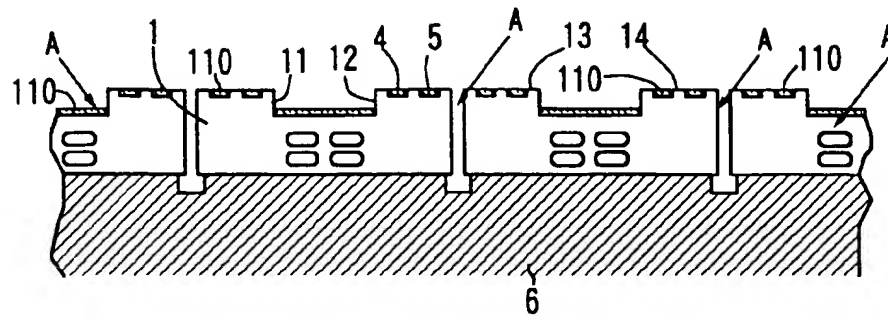


FIG. 13

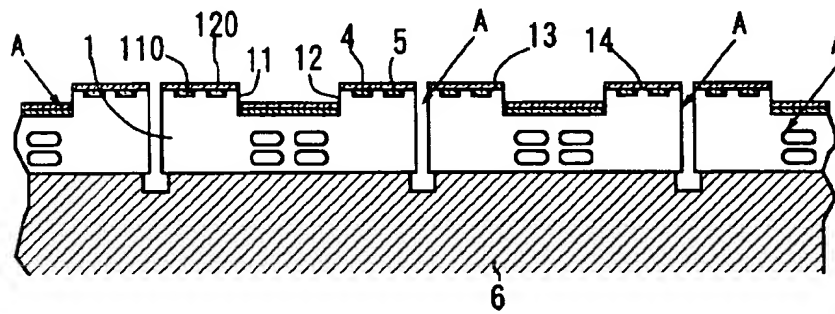


FIG. 14

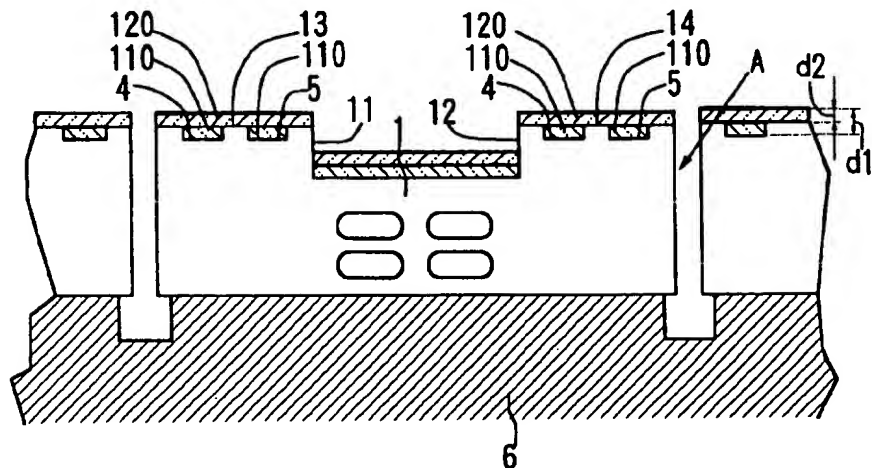


FIG. 15

# THIN FILM MAGNETIC HEAD AND MANUFACTURING METHOD THEREOF

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a thin film magnetic head employed in a magnetic recording/reproduction apparatus such as a magnetic disk apparatus, and a manufacturing method thereof.

### 2. Discussion of Background

In order to assure high density recording in magnetic disk apparatuses, the recording track width of thin film magnetic heads has been reduced to  $1.0\mu\text{m}$  or less in recent years. One of the prior art methods to achieve such a small recording track width is to machine the air bearing surface (ABS) of the slider. Indented portions having a specific depth are obtained by polishing the surface of the slider facing opposite the medium, defining a pattern by removing the area that contains the end surface of the magnetic film through the Focused Ion Beam (FIB) etching technique or through photolithography, and machining the air bearing surface in conformance with the pattern thus defined by employing a means such as ion milling.

IEEE Transactions on Magnetics Vol. 27, No. 6, November 1991, for instance, discloses a reduced track width obtained by applying the FIB etching technique on the ABS of the slider, and IEEE Transactions on Magnetics Vol. 30, No. 6, November 1994 discloses a thin film magnetic head having a reduced track width obtained by machining the slider through photolithography.

During the machining processes described above, the end surface of the magnetic film constituting the pole tip becomes exposed within the indented portions. As a means for protecting this end surface from oxidation or corrosion, a single protective film is formed over the entire surface facing opposite the medium including the ABS and the indented portions. Normally, the protective film is constituted of diamond-like carbon (DLC).

However, since the protective film has a consistent thickness and is formed onto the ABS as well as inside the indented portions, this structure poses a problem in that in order to cover the entire end surface of the magnetic film exposed within the indented portions, it is necessary to use a rather thick protective film. This means that the protective film formed onto the air bearing surface is thick as well, causing spacing loss which in turn leads to deteriorated electromagnetic conversion characteristics.

The problem described above occurs whenever an area containing a pole tip is removed and thus, it is not limited to the process performed to achieve a reduction in the track width.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide a thin film magnetic head in which the end surface of the magnetic film constituting a pole tip is reliably protected from oxidation, corrosion and the like while achieving a reduction in spacing loss.

It is a further object of the present invention to provide a suitable method for manufacturing the thin film magnetic head described above.

In order to achieve these objects, the thin film magnetic head according to the present invention comprises a slider, at least one inductive thin film magnetic transducer and a protective film. The slider having a base body surface facing

opposite a medium, is provided with indented portions recessed from the surface facing opposite the medium.

The inductive thin film magnetic transducer has a pole tip of which the front end emerges at the base body surface and the indented portions.

The protective film covers the base body surface as well as the indented portions. The thickness of the protective film at the indented portions is larger than the thickness of the protective film at the base body surface.

As described above, in the thin film magnetic head according to the present invention, the inductive thin film magnetic transducer is provided with a pole tip whose front end emerges at the base body surface and the indented portions. By adopting this structure, electromagnetic conversion characteristics corresponding to the extent of the indentation of the pole tip imparted by the indented portions are realized. A typical objective to remove an area of the base body surface where a pole tip is situated, is to achieve a reduction in the track width. In this case, since the width of the pole tip in the direction of the tracks that intersects the direction in which the medium travels, is reduced by the formation of indented portions, a flying type thin film magnetic head having a track width that is reduced in correspondence to the extent of the indentation of the area where the pole tip is situated, is achieved.

The protective film is formed onto the base body surface. As a result, the front end of the magnetic film constituting the pole tip being exposed inside the indented portions is covered by the protective film so that the front end of the magnetic film is protected from oxidation and corrosion.

The film thickness of the protective film at the indented portions is set larger than the film thickness of the protective film at the base body surface. In other words, the film thickness of the protective film formed onto the base body surface is smaller than the film thickness of the protective film formed inside the indented portions. Thus, with the protective film covering the base body surface being thinner, the spacing loss can be reduced, while at the same time covering the front end of the magnetic film which constitutes the pole tip with the protective film.

## BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, structural features and advantages of the present invention are explained in further detail in reference to the attached drawings illustrating the embodiments, wherein:

FIG. 1 is a perspective of the thin film magnetic head according to the present invention;

FIG. 2 is a sectional view of the thin film magnetic head illustrated in FIG. 1;

FIG. 3 is a perspective of the thin film magnetic head illustrated in FIGS. 1 and 2 in a partial enlargement;

FIG. 4 is a sectional view taken along line 4—4 of FIG. 3;

FIG. 5 is an enlarged sectional view of the thin film magnetic transducer in another embodiment of the thin film magnetic head according to the present invention;

FIG. 6 is an enlarged sectional view of the thin film magnetic transducer in another embodiment of the thin film magnetic head according to the present invention;

FIG. 7 illustrates a step included in the method for manufacturing the thin film magnetic head according to the present invention;

FIG. 8 illustrates a step following the step illustrated in FIG. 7;

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FIG. 9 illustrates a step following the step illustrated in FIG. 8;

FIG. 10 illustrates a step following the step illustrated in FIG. 9;

FIG. 11 illustrates a step following the step illustrated in FIG. 10;

FIG. 12 illustrates a step following the step illustrated in FIG. 11;

FIG. 13 illustrates a step following the step illustrated in FIG. 12;

FIG. 14 illustrates a step following the step illustrated in FIG. 13; and

FIG. 15 is a partial enlargement of FIG. 14.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1 to 4 in which dimensions are exaggerated, the thin film magnetic head according to the present invention includes a slider 1, at least one inductive thin film magnetic transducer 2 and a protective film 10.

The slider 1 is provided with rail portions 11 and 12 at a base body surface, with surfaces 13 and 14 of the rail portions 11 and 12 respectively being air bearing surfaces. The number of rail portions 11 and 12 is not restricted to two. For instance, the slider 1 may be provided with only 1, or more than 2 rail portions, or may even constitute a flat surface having no rail portion. In addition, the base body surface may take on various geometric shapes to improve flying characteristics and the like. The present invention may be adopted in combination with any of these types of sliders.

The inductive thin film magnetic transducer 2 situated at the trailing edge TR of the slider 1 is provided with a first pole tip P1 and a second pole tip P2. The front ends of the first pole tip P1 and the second pole tip P2 emerge at the surface 13 or 14 facing opposite the medium. The first pole tip P1 and the second pole tip P2 of the inductive thin film magnetic transducer 2 are exposed inside the indented portions 4 and 5. The depth, width, shape and the like of the indented portions 4 and 5 are varied in correspondence to the functions to be satisfied by the indented portions 4 and 5.

In the embodiment, the indented portions 4 and 5 are provided on two sides along the track direction b1, delimiting the first pole tip P1 and the second pole tip P2. Thus, the width W0 of the first pole tip P1 and the second pole tip P2 in the track direction b1 intersecting the direction a1 in which the medium travels is defined by the indented portions 4 and 5 provided at the surface 13 or 14 facing opposite the medium. In the embodiment, the indented portions 4 and 5 are used to define the width W0 of the pole tip P2 in the track direction b1. The indented portions 4 and 5 are formed to achieve a depth of 0.5 to 1.0  $\mu\text{m}$  and a width of 30 to 100  $\mu\text{m}$ , for instance.

The surfaces 100 of the protective film 10 formed onto the surfaces 13 and 14 are utilized as air bearing surfaces. The film thickness d1 of the protective film 10 at the indented portions 4 and 5 is set larger than the film thickness d2 of the protective film 10 at the surfaces 13 and 14 facing opposite the medium. The film thickness d1 of the protective film 10 at the indented portions 4 and 5 is measured from the bottom surfaces of the indented portions 4 and 5 to the superficial surface of the protective film 10. The film thickness d2 of the protective film 10 at the surfaces 13 and 14 is measured from the surfaces 13 and 14 facing opposite the medium to the surface 100 of the protective film 10. For instance, the film thickness d1 of the protective film 10 formed inside the

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indented portions 4 and 5 may be set within a range of approximately 16 to 18 nm or to a value exceeding this range, and the film thickness d2 of the protective film 10 formed onto the surfaces 13 and 14 may be set within the range of approximately 6 to 8 nm. Since the indented portions 4 and 5 are formed to achieve a depth of 0.5 to 1.0  $\mu\text{m}$  and a width of 30 to 100  $\mu\text{m}$ , the thickness d1 of the protective film 10 formed inside the indented portions 4 and 5 is extremely small relative to the depth of the indented portions 4 and 5. In the figures, the thicknesses d1 and d2 of the protective film 10 are illustrated in an exaggerated manner.

As explained above, in the thin film magnetic head according to the present invention, the inductive thin film magnetic transducer 2 includes the first pole tip P1 and the second pole tip P2 whose front ends emerge at the surfaces 13 and 14 and the indented portions 4 and 5. This structure realizes electromagnetic conversion characteristics that correspond to the extent of the indentation of the first pole tip P1 and the second pole tip P2 effected by the indented portions 4 and 5 and the resulting shape, depth, width and the like of the first pole tip P1 and the second pole tip P2.

In the embodiment, the indented portions 4 and 5 are provided on two sides along the track direction b1, delimiting the first pole tip P1 and the second pole tip P2. The width W0 of the first pole tip P1 and the second pole tip P2 in the track direction b1 intersecting the direction a1 in which the medium travels, is essentially defined by the indented portions 4 and 5 formed onto the surfaces 13 and 14 facing opposite the medium. By adopting this structure, a flying type thin film magnetic head having a recording track width W0 which is reduced in correspondence to the extent of indentation is achieved.

The protective film 10 covers the surface of the slider 1 facing opposite the medium. Consequently, the first pole tip P1 and the second pole tip P2 being exposed inside the indented portions 4 and 5 are covered by the protective film 10 so as to prevent oxidation and corrosion. Since the protective film 10 is also formed onto the surfaces 13 and 14 of the slider 1, the surfaces 100 of the protective film 10 function as air bearing surfaces.

The film thickness d1 of the protective film 10 formed inside the indented portions 4 and 5 is larger than the film thickness d2 of the protective film 10 formed onto the surfaces 13 and 14. In other words, the film thickness d2 of the protective film 10 at the surfaces 13 and 14 is smaller than the film thickness d1 of the protective film 10 at the indented portions 4 and 5. Thus, the first pole tip P1 and the second pole tip P2 exposed within the indented portions 4 and 5 are completely covered by the protective film 10 and at the same time, the film thickness d2 of the protective film 10 formed onto the surfaces 13 and 14 can be reduced to minimize the spacing loss. The protective film 10 is formed so as to achieve a film thickness d2 at the surfaces 13 and 14 equal to or less than 10 nm, e.g., approximately 6 to 8 nm. The protective film 10 may contain a DLC film or a nitride film. Furthermore, the protective film 10 may include a silicon film which may be employed as a base film for the DLC film.

Referring now to FIG. 5, the protective film 10 is constituted of a DLC film 102 having a film thickness of approximately 6 nm provided onto an Si film 101 having a film thickness of approximately 2 nm. The surfaces 13 and 14 are laminated once with this double-layered protective film 10 while the indented portions 4 and 5 are laminated twice or more with this double-layered protective film 10

The base film constituted of the Si film 101 increases the strength with which the protective film 10 is deposited onto the slider which is constituted of a ceramic structure such as  $Al_2O_3/TiC$ .

The present invention may be adopted regardless of the shape of the indented portions 4 and 5. In addition, the planar shape of the protective film 10 is arbitrary and may be a flat surface, a textured surface or a surface with indentations and projections. Since the surfaces 100 of the protective film 10 constitute air bearing surfaces, the ABS characteristics can be controlled by selecting a specific surface form for them.

Referring again to FIGS. 1 to 4, the inductive thin film magnetic transducers 2 situated at the trailing edge TR of the slider 1 are each provided with a first magnetic film 21, a second magnetic film 22, a coil film 23, a gap film 24, an insulating film 25 and a protective film 26. The gap film 24 and the protective film 26 are constituted of alumina or the like and the insulating film 25 is constituted of an organic resin. The end surfaces of the first magnetic film 21 and the second magnetic film 22 constitute a first pole tip P1 and a second pole tip P2 respectively, facing opposite each other over the gap film 24 having an extremely small thickness. Write is performed at the first pole tip P1 and the second pole tip P2. The yokes of the first magnetic film 21 and the second magnetic film 22 are linked with each other to complete a magnetic circuit at a back gap area located on the side opposite from the side where the first pole tip P1 and the second pole tip P2 are provided. The coil film 23 is formed in a spiral shape around the area where the yokes are linked to the insulating film 25. The two ends of the coil film 23 are made electrically continuous with bumps 27 and 28 (see FIG. 1). The number of turns and the number of layers of the coil film 23 are arbitrary.

According to the present invention, the thin film magnetic transducers 2 are situated within the area where the indented portions 4 and 5 are provided and is an inductive transducer. The inductive thin film magnetic transducers 2 may be utilized for both write and read operations in magnetic recording/reproduction. Alternatively, the inductive thin film magnetic transducers 2 may be employed exclusively for write operations, and separate thin film magnetic transducers that use the magnetoresistance effect (hereafter referred to as MR elements) may be provided for read operations.

In the embodiment, the inductive magnetic transducers 2 are employed exclusively for write operations and the MR elements 3 are provided for read operations. The MR elements 3 may adopt any of the various film structures that have been proposed and put into practical use to date. These film structures include one employing anisotropic MR elements constituted of permalloy or the like and those using a giant magnetoresistive (GMR) film. The present invention may be adopted in combination with any of these various types of MR elements. The MR elements 3 are each provided between a first shield film 31 and the first magnetic film 21 which also functions as a second shield film, inside an insulating film 32. The insulating film 32 is constituted of alumina or the like. Each of the MR elements 3 is connected to bumps 33 and 34 (see FIG. 1).

The thin film magnetic transducers 2 and 3 positioned at the trailing edge TR of the slider 1 are provided at either one of the rail portions 11 and 12 or at both of them. The medium traveling direction a1 matches the direction in which air flows out when the medium travels at high speed. Bumps 27 and 28 connected to the thin film magnetic transducers 2 and bumps 33 and 34 connected to the MR elements 3 are provided at an end surface of the slider 1.

Referring to FIG. 6 wherein the same reference numbers are assigned to components identical to those illustrated in FIGS. 1 to 5, while the indented portions 4 and 5 are not illustrated, their structure and shape are identical to those in the embodiment illustrated in FIGS. 1 to 5. Of the first magnetic film 21 and the second magnetic film 22, the second magnetic film 22 includes a third magnetic layer 221 that is in contact with a gap film 24 at the pole tip P2 and a fourth magnetic layer 222 that is deposited in contact with the third magnetic layer 221 (to the right in FIG. 6). By adopting this structure, the material characteristics of the third magnetic layer can be differentiated from the material characteristics of the fourth magnetic layer to achieve required improvements in the characteristics.

For instance, the saturation magnetic flux density of the third magnetic layer 221 may be selected at a value larger than that representing the saturation magnetic flux density of the fourth magnetic layer 222. By making such a selection, the high frequency recording characteristics can be improved. As a specific example in which the saturation magnetic flux density of the third magnetic layer 221 is selected at a value larger than that representing the saturation magnetic flux density of the fourth magnetic layer 222, a combination of a fourth magnetic layer 222 constituted of a Ni (80%)—Fe (20%) permalloy and a third magnetic layer 221 constituted of a Ni (50%)—Fe (50%) permalloy may be adopted. The third magnetic film 221 having the composition described above becomes corroded more readily compared to the fourth magnetic film 221 having the composition described above, and thus, it is concluded that the protective film structure according to the present invention is extremely effective.

As another effective means for improving the high frequency recording characteristics, the resistivity of the third magnetic layer 221 may be set larger than the resistivity of the fourth magnetic layer 222.

It is also effective to set the abrasion resistance of the third magnetic layer 221 higher than the abrasion resistance of the fourth magnetic layer 222. In this case, the abrasion of the third magnetic layer 221 that is provided adjacent to the gap film 24 and practically defines the gap thickness can be avoided to achieve stable electromagnetic conversion characteristics. Although a detailed explanation is omitted, a similar structure may be adopted in the first magnetic film 21, as well.

In addition, the structure of the pole tips in the thin film magnetic head is not restricted to that in the embodiments shown, and any of various pole structures that have been proposed to date or that will be proposed in the future may be adopted. For instance, the present invention may be adopted in combination with pole tips each adopting a multilayer film structure having two or more layers or in combination with only one of the two pole tips adopting a multilayer film structure. Furthermore, when a pole tip adopts a multilayer film structure, a portion of the magnetic film constituting the pole tip may be formed at a position receded from the surface facing opposite the medium so that it is not exposed at the base body surface. Moreover, miniaturization of the thin film magnetic head may be achieved by adopting a structure in which an indented portion is provided at one surface of the base body and in which the essential portion of an inductive thin film magnetic transducer including the coil portion is positioned inside the indented portion.

Next, in reference to FIGS. 7 to 15, the method for manufacturing the thin film magnetic head according to the present invention is explained.

First, as illustrated in FIG. 7, a large number of thin film magnetic heads A are arrayed on a jig 6, each secured at one surface by a means such as bonding. The thin film magnetic heads A each have undergone the grinding process performed on the rails 11 and 12 and the polishing process performed on the surfaces 13 and 14 and thus, achieve a required gap depth. Although not shown, the array of individual thin film magnetic heads A illustrated in FIG. 7 is achieved by cutting a bar of aligned thin film magnetic heads after mounting the bar onto the jig 6.

Next, as illustrated in FIG. 8, a resist film 7 constituted of an organic resist film 72 formed onto a support body 71 is laminated onto the surfaces 13 and 14 to transfer the resist film 72.

Following the step described above, as illustrated in FIG. 9, the support body 71 is removed. The support body 71 is constituted of a flexible film such as polyethylene terephthalate. The resist film 72 is normally constituted by using a photosensitive resist, which may be either a negative type or a positive type photosensitive resist. In the embodiment, a positive type photosensitive resist is used. The positive type photosensitive resist may be, for instance, the product PFR3004 (manufactured by Nippon Synthetic Rubber Co. Ltd.). At the resist film 7, the resist film 72 is formed through spin coating. The film thickness of the resist film 72 is set at a consistent thickness that allows for the processing of the surfaces 13 and 14. The transfer may be achieved through thermal compression bonding employing a hot roll 8 (see FIG. 8).

After transferring the resist film 72 onto the surfaces 13 and 14, it is exposed and developed using a mask 9 having a pattern required for forming indented portions, as illustrated in FIG. 10. Since the resist film 72 is constituted using a positive type photosensitive resist in the embodiment, the exposed areas are removed during the developing process. The developing process is achieved by etching the exposed portions with an alkaline developing solution. Subsequently, processing such as ion milling, chemical etching or the like is performed on the surfaces 13 and 14 over the resist film 72 that has remained in place during the patterning process. Consequently, as illustrated in FIG. 11, the indented portions 4 and 5 achieving a specific pattern and a specific depth are obtained.

Next, as illustrated in FIG. 12, without removing the resist film 72, a first protective film 110 is formed onto the resist film 72. The first protective film 110 is formed onto the surface of the slider 1 including the insides of the indented portions 4 and 5, but not onto the surfaces 13 and 14 that are covered by the resist film 72. The first protective film 110 may be formed through, for instance, sputtering. The first protective film 110 is formed to achieve a film thickness of, for instance, 10 nm or larger.

Next, as illustrated in FIG. 13, the resist film 72 is removed. The first protective film 110 deposited onto the resist film 72 is removed together with the resist film 72.

In the following step, as illustrated in FIG. 14, a second protective film 120 is formed through sputtering or the like over the entire surface of the slider 1 that faces opposite a medium. The second protective film 120 is formed to achieve a film thickness of, for instance, approximately 6 to 8 nm. Since the first protective film 110 has already been formed inside the indented portions 4 and 5, the film thickness d1 of the protective film 10 formed inside the indented portions 4 and 5 is the sum of the film thickness of the first protective film 110 formed through the first lamination and the film thickness d2 of the second protective film

120 formed through the second lamination as illustrated in FIG. 15. The film thickness of the protective film 10 formed onto the surfaces 13 and 14 at the slider 1 is only made up of the film thickness d2 of the second protective film 120 formed through the second lamination. As a result, the film thickness d1 of the protective film 10 formed inside the indented portions 4 and 5 is bound to be larger than the film thickness d2 of the protective film 10 formed onto the surfaces 13 and 14.

The method adopted in the embodiment described above is characterized by the two-stage process in which the first protective film 110 is first formed onto the surface of the slider 1 facing opposite a medium and inside the indented portions 4 and 5 and then the second protective film 120 is formed onto the surfaces 13 and 14 and for a second time inside the indented portions 4 and 5.

Alternatively, the order of the formation of the first protective film and the second protective film may be reversed. In this two-stage process a first protective film 110 is formed onto the surfaces 13 and 14 as well as inside the indented portions 4 and 5, after which a second protective film 120 is formed onto the first protective film 110 where the indented portions 4 and 5 are situated.

While the explanation is given on an example in which the resist film 7 constituted by forming the organic resist film 72 on the support body 71 in reference to the embodiment, a spin-coat method or the like may be adopted instead. In addition, while the explanation is given using an example in which the pattern is formed using a photoresist, another high precision pattern formation technology such as the Focused Ion Beam (FIB) machining technology may be adopted instead.

While the invention has been particularly shown and described with respect to preferred embodiments thereof by referring to the attached drawings, the present invention is not limited to these examples and it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit, scope and teaching of the invention.

The present application is based on Japanese priority application number 10-162683, filed with the Japanese Patent Office on Jun. 10, 1998, the entire contents of which are hereby incorporated by reference.

What is claimed is:

1. A thin film magnetic head comprising:

a slider having a base body surface facing opposite a medium, said base body surface being provided with indented portions;

at least one inductive thin film magnetic transducer having a pole tip of which a front end emerges at said base body surface and said indented portions, delimiting said pole tip; and

a protective film covering said indented portions and said base body surface, with the thickness of said protective film at said indented portions being larger than the thickness at said base body surface.

2. The thin film magnetic head of claim 1, wherein:

said indented portions define a track width of said pole tip.

3. The thin film magnetic head of claim 1, wherein:

said protective film includes a diamond-like carbon film.

4. The thin film magnetic head of claim 3, wherein:

said protective film includes a silicon film being a base film of said diamond-like carbon film.

5. The thin film magnetic head of claim 1, wherein:

said protective film includes a nitride film.

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6. The thin film magnetic head of claim 1, wherein:  
said indented portions are provided on two sides of said pole tip, delimiting said pole tip along the direction of data tracks.
7. The thin film magnetic head of claim 1, wherein:  
said pole tip includes a first pole tip and a second pole tip facing opposite each other via a gap film; and  
said indented portions essentially define the width of at least either said first pole tip or said second pole tip in the direction of data tracks.
8. The thin film magnetic head of claim 7, wherein:  
the width of said first pole tip in the direction of the tracks is essentially defined by said indented portions.
9. The thin film magnetic head of claim 7, wherein:  
widths of said first pole tip and said second pole tip in the direction of the tracks are essentially defined by said indented portions.
10. The thin film magnetic head of claim 7, wherein:  
at least either said first pole tip or said second pole tip includes two magnetic films having different material characteristics from each other and are provided adjacent to each other.
11. The thin film magnetic head of claim 10, wherein:  
of said two magnetic films, a magnetic film adjacent to a gap film has a saturation magnetic flux density larger than the saturation magnetic flux density of the other magnetic film.
12. The thin film magnetic head of claim 10, wherein:  
the magnetic film adjacent to a gap film has a resistivity higher than the resistivity of the other magnetic film.
13. The thin film magnetic head of claim 10, wherein:  
the abrasion resistance of the magnetic film adjacent to a gap film is better than the abrasion resistance of the other magnetic film.
14. The thin film magnetic head of claim 10, having a thin film magnetic transducer utilizing the magnetoresistance effect.
15. A method for manufacturing a thin film magnetic head, said thin film magnetic head comprising:  
a slider having a base body surface facing opposite a medium, said base body surface being provided with indented portions;  
at least one inductive thin film magnetic transducer having a pole tip of which a front end emerges at said base body surface and said indented portions; and

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- a protective film covering said indented portions and said base body surface, with the thickness of said protective film at said indented portions being larger than the thickness at said base body surface;
- said method comprising the steps of:  
forming said indented portions on said base body surface;  
forming a first protective film into said indented portions; and  
forming a second protective film onto said base body surface and said first protective film.
16. A method for manufacturing a thin film magnetic head, said thin film magnetic head comprising:  
a slider having a base body surface facing opposite a medium, said base body surface being provided with indented portions;  
at least one inductive thin film magnetic transducer having a pole tip of which a front end emerges at said base body surface and said indented portions; and  
a protective film covering said indented portions and said base body surface, with the thickness of said protective film at said indented portions being larger than the thickness at said base body surface;
- said method comprising the steps of:  
forming said indented portions on said base body surface;  
forming a first protective film that covers said base body surface and the bottom surface of said indented portions;  
forming a second protective film onto said first protective film where said indented portions are provided.
17. The method of claim 15, wherein:  
said forming of said indented portions on said base body surface defines a track width of said pole tip.
18. The method of claim 16, wherein:  
said forming of said indented portions on said base body surface defines a track width of said pole tip.
19. The method of claim 15, wherein:  
said forming of said indented portions includes forming said indented portions on two sides of said pole tip to define a track width of said pole tip.
20. The method of claim 16, wherein:  
said forming of said indented portions includes forming said indented portions on two sides of said pole tip to define a track width of said pole tip.

\* \* \* \* \*





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(12) **United States Patent**  
**Mino**

(10) **Patent No.:** **US 6,188,544 B1**  
(45) **Date of Patent:** **Feb. 13, 2001**

(54) **THIN-FILM MAGNETIC HEAD WITH  
THREE-LAYER POLE TOP STRUCTURE**

(75) **Inventor:** Tetsuya Mino, Chiba (JP)

(73) **Assignee:** TDK Corporation, Tokyo (JP)

(\*) **Notice:** Under 35 U.S.C. 154(b), the term of this  
patent shall be extended for 0 days.

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.<sup>7</sup>** ..... G11B 5/147; G11B 5/127

(52) **U.S. Cl.** ..... 360/126; 360/317

(58) **Field of Search** ..... 360/125, 126,  
360/119, 317

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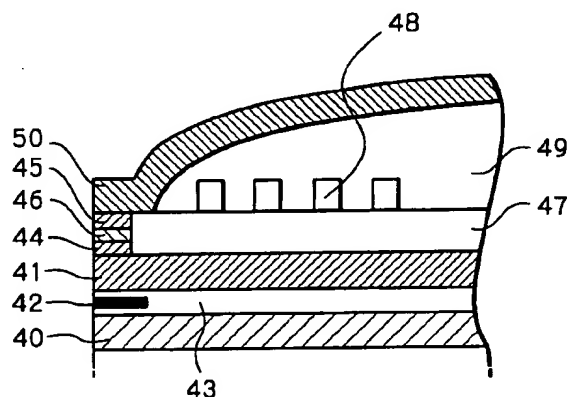
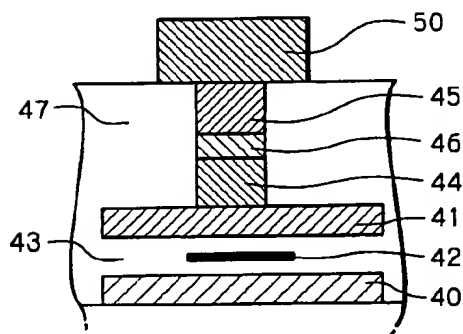
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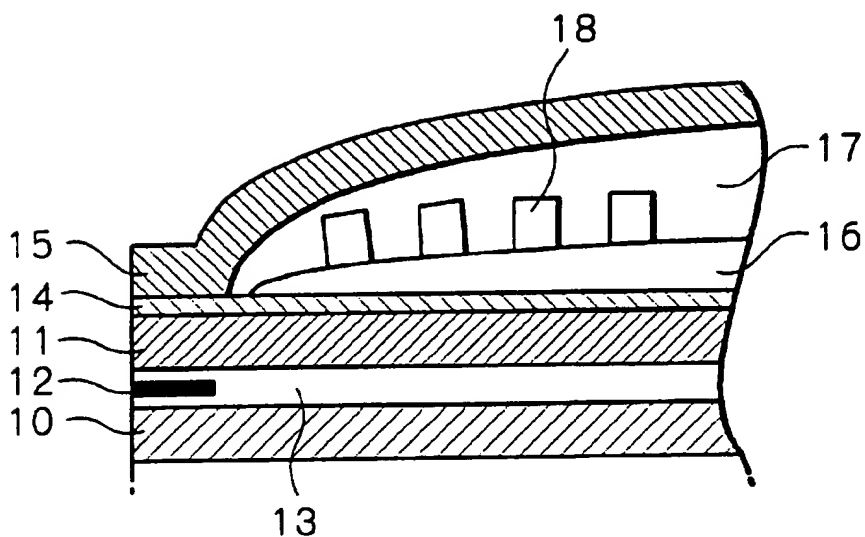
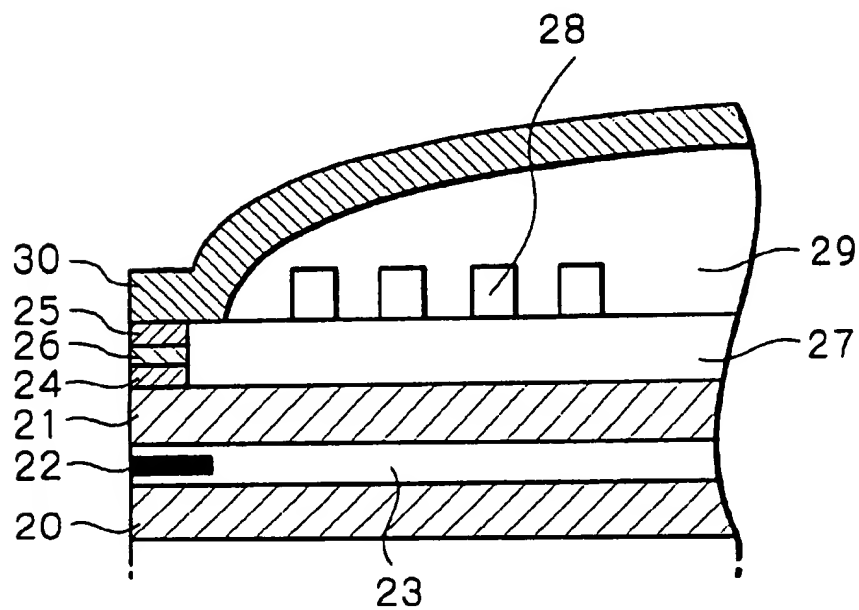
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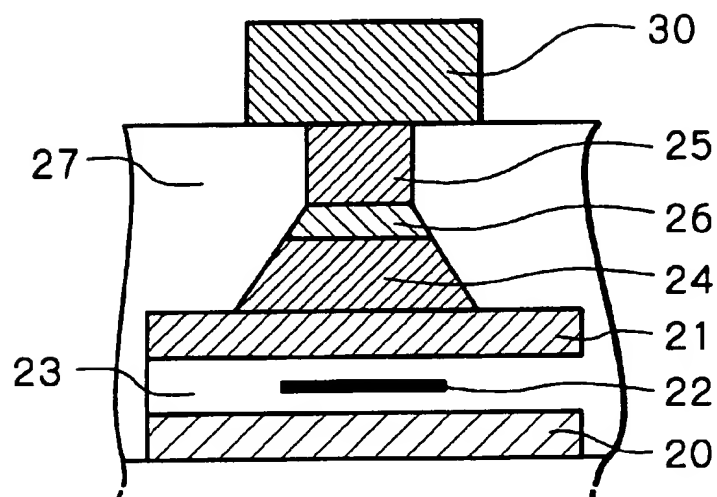
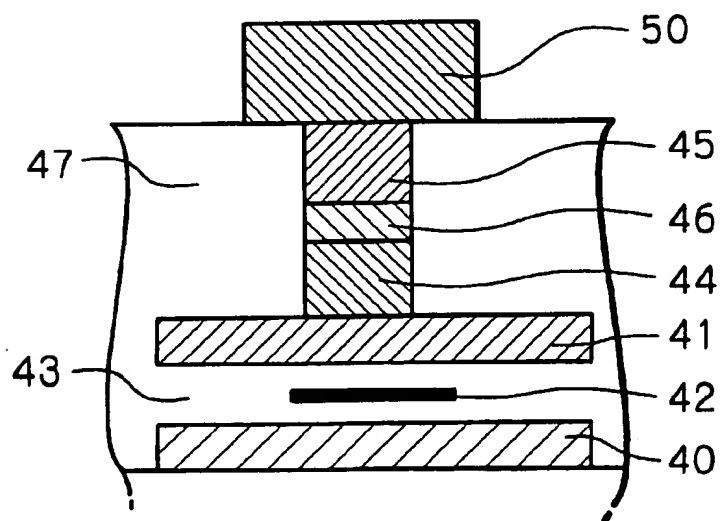
(57) **ABSTRACT**

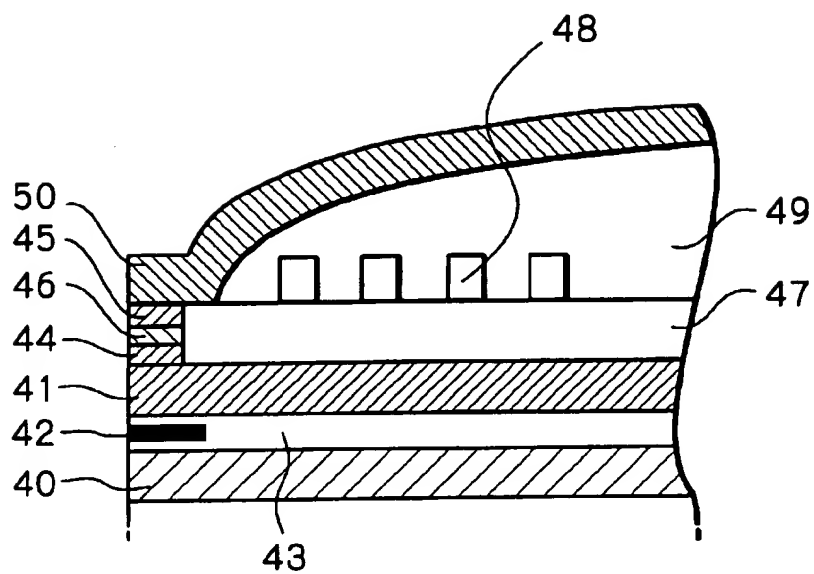
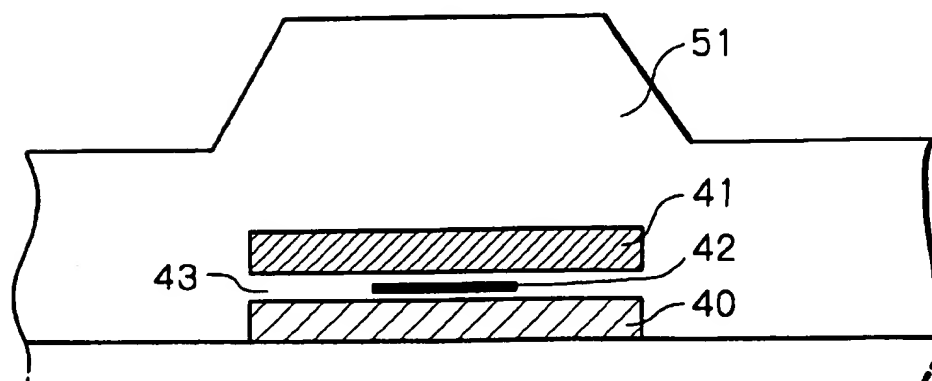
A thin-film magnetic head includes an ABS and a three-layer  
pole tip structure located between the ABS and a position at  
a predetermined height from the ABS. The structure consists  
of a first pole, a recording gap layer and a second pole. The  
recording gap layer is made of a material having a etching  
rate equal to or higher than that of a material for making the  
first and second poles.

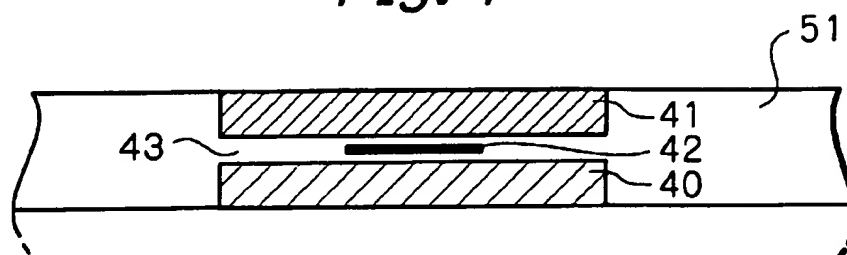
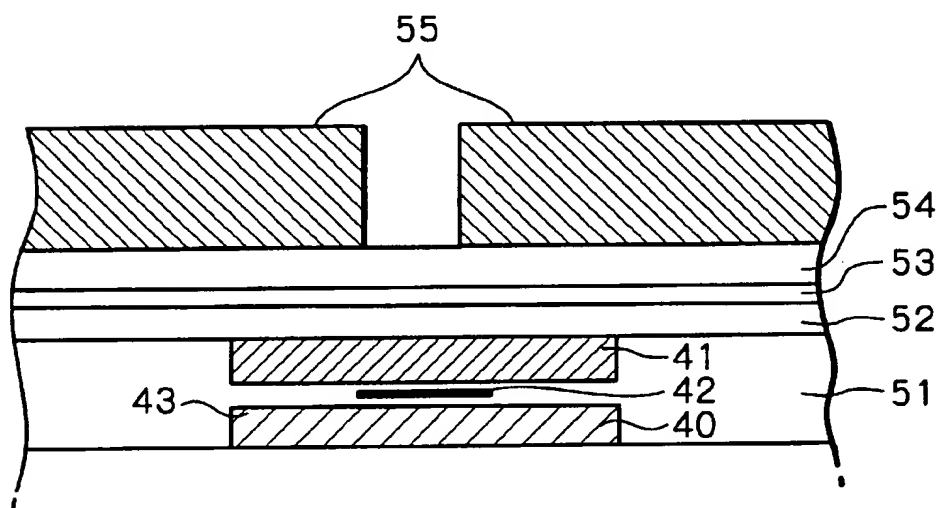
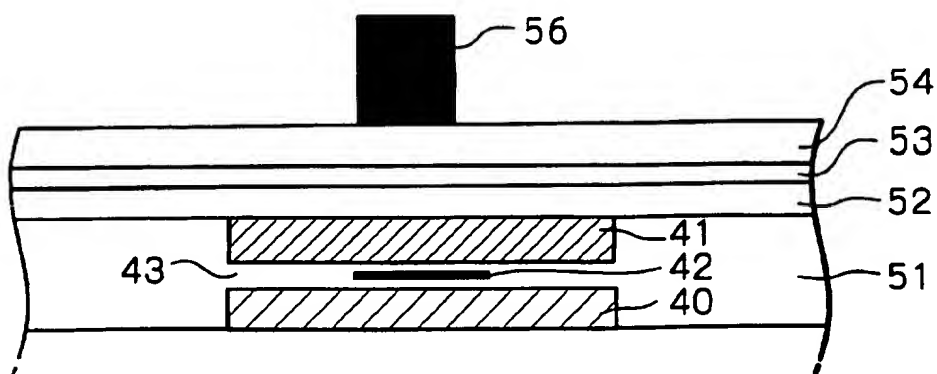
**6 Claims, 5 Drawing Sheets**

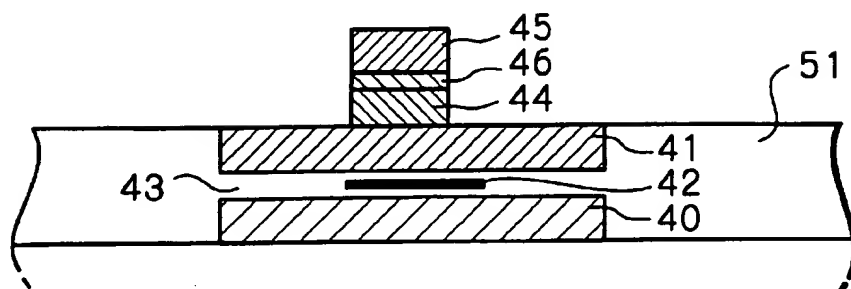
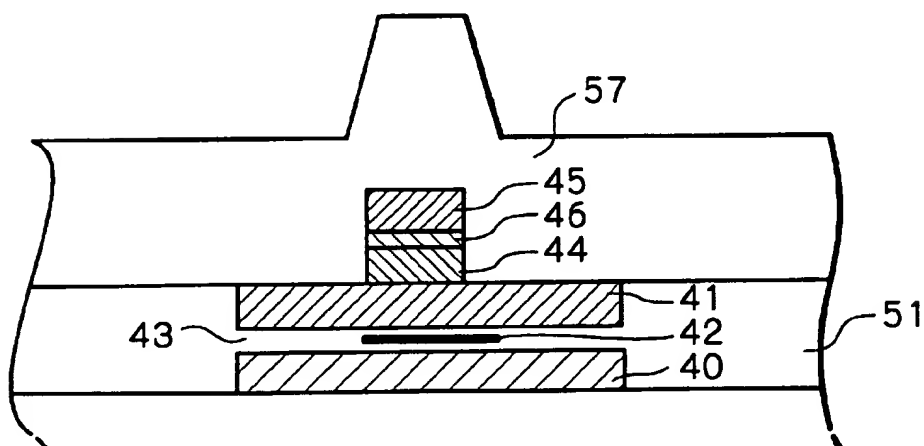
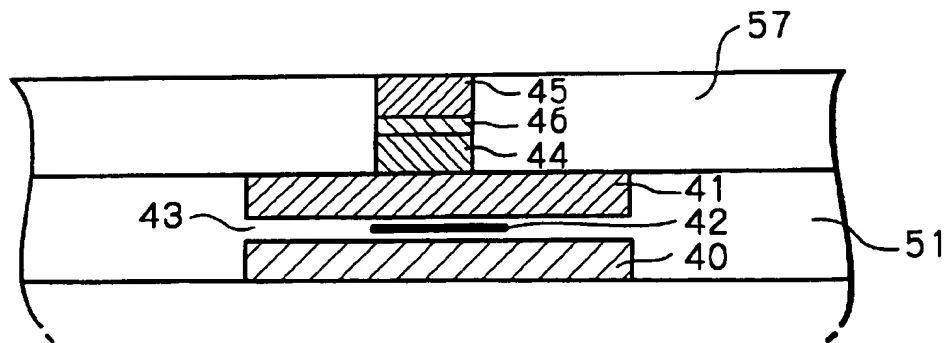


*Fig. 1* PRIOR ART*Fig. 2* PRIOR ART

*Fig. 3**Fig. 4*

*Fig. 5**Fig. 6*

*Fig. 7**Fig. 8**Fig. 9*

*Fig. 10**Fig. 11**Fig. 12*

# THIN-FILM MAGNETIC HEAD WITH THREE-LAYER POLE TOP STRUCTURE

## FIELD OF THE INVENTION

The present invention relates to a thin-film magnetic head provided with at least an inductive recording transducer element and to a method of manufacturing the head.

## DESCRIPTION OF THE RELATED ART

FIG. 1 is a cross-sectional view perpendicular to the plane of the air bearing surface (ABS), illustrating an example of a conventional composite type thin-film magnetic head with an inductive recording head part and a magnetoresistive (MR) reproducing head part.

In the figure, the reference numeral 10 denotes a lower shield layer of the MR reproducing head part, 11 denotes an upper shield layer of the MR head part, which also acts as a lower pole of an inductive recording head part, 12 denotes a MR layer provided through an insulating layer 13 between the lower shield layer 10 and the upper shield layer 11, 14 denotes a recording gap layer of the recording head part, 15 denotes an upper pole, 16 denotes a lower insulating layer deposited on the recording gap layer 14, 18 denotes a coil conductor formed on the lower insulating layer 16, and 17 denote an upper insulating layer deposited so as to cover the coil conductor 18. The upper pole 15 is magnetically connected with the lower pole (upper shield layer) 11 at its rear portion so as to constitute a magnetic yoke together with the lower pole 11.

As apparent from the figure, since the recording gap layer 14 of the conventional thin-film magnetic head is formed even under the coil conductor for generating a recording magnetic field, it is necessary to use materials having a high thermal conductivity. Thus, as the material of the recording gap layer 14, aluminum oxide ( $Al_2O_3$ ) with comparatively high thermal conductivity has typically been used.

Recently, demand for higher recording density has made a recording track width narrower, and therefore a submicron width of the pole of the recording head part has been needed. To cope with such narrower pole width, a thin-film magnetic head is formed in a manner that only the recording pole portion is separated from other portions. That is, a three-layer pole structure with a lower pole tip element, a recording gap layer and an upper pole tip element is formed at only a pole tip region located between the ABS and a position at a predetermined height from the ABS in the recording head part, and an upper yoke and a lower yoke are magnetically connected to the top surface and the bottom surface of this pole tip structure, respectively.

FIGS. 2 and 3 illustrate an example of a conventional composite type thin-film magnetic head having such a three-layer pole tip structure. FIG. 2 is a cross-sectional view perpendicular to the plane of the ABS, and FIG. 3 is a schematic ABS view. In these figures, the reference numeral 20 denotes a lower shield layer of the MR reproducing head part, 21 denotes an upper shield layer of the MR head part, which also acts as a lower auxiliary pole of an inductive recording head part, 22 denotes a MR layer provided through an insulating layer 23 between the lower shield layer 20 and the upper shield layer 21, 24 denotes a lower pole tip element of the inductive recording head part, 25 denotes an upper pole tip element, 26 denotes a recording gap layer formed between the lower pole tip element 24 and the upper pole tip element 25, 27 denotes a lower insulating layer deposited on the upper shield layer 21 and around a three-layer pole structure consisting of the lower pole tip

element 24, the recording gap layer 26 and the upper pole tip element 25, 28 denotes a coil conductor formed on the lower insulating layer 27, 29 denotes an upper insulating layer deposited so as to cover the coil conductor 28, and 30 denotes an upper auxiliary pole formed on the upper insulating layer 29 and deposited to contact with the upper pole tip element 25. The upper auxiliary pole 30 is magnetically connected with the lower auxiliary pole (upper shield layer) 21 at its rear portion so as to constitute a magnetic yoke together with the lower auxiliary pole 21.

In manufacturing the above-mentioned thin-film magnetic head in which only the recording pole portion is separated from other portions, when three-layer pole structure consisting of the lower pole tip element 24, the recording gap layer 26 and the upper pole tip element 25 is formed by a dry etching process such as ion milling, conventional use of  $Al_2O_3$  as a material of the recording gap layer causes its shape control to become difficult. That is, since  $Al_2O_3$  has a lower etching rate than that of magnetic materials used for the lower and upper pole tip elements 24 and 25 of the three-layer pole structure, shape control, such as formation of the side surface of the three-layer pole structure to make perpendicular to the top surface of the upper shield layer 21 is very difficult. In other words, when the three-layer pole structure is patterned by a dry etching process, the side surface of the  $Al_2O_3$  gap layer 26 is not easily etched due to the lower etching rate of  $Al_2O_3$  than that of the magnetic material of the upper pole 25. Thus, the side surfaces of the patterned recording gap layer 26 incline with respect to that of the upper pole layer as shown in FIG. 3. In addition, the side surfaces of the lower pole layer 24 below the recording gap layer 26 also incline as well as the recording gap layer 26, thereby generating problems such as increase of recording track width and side fringing.

In order to enhance the etching rate of  $Al_2O_3$ , use of a reactive ion etching (RIE) may be considered. However, when the three-layer pole structure mentioned above is etched, not only etching gas must be changed for every layer, but also an etching device should be formed so as to correspond to the etching gas for  $Al_2O_3$  such as chlorine series. Additionally, a countermeasure for corrosion should be also considered.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a thin-film magnetic head and a method of manufacturing the same, whereby a little side fringing and stable recording properties can be realized even in a narrower track.

According to the present invention, a thin-film magnetic head includes an ABS and a three-layer pole tip structure located between the ABS and a position at a predetermined height from the ABS. The structure consists of a first pole, a recording gap layer and a second pole. The recording gap layer is made of a material having an etching rate equal to or higher than that of a material for making the first and second poles.

According to the present invention, furthermore, a thin-film magnetic head has a MR reproducing head part, an inductive recording head part multilayered with the reproducing head part, and an ABS. The recording head part includes a three-layer pole tip structure located between the ABS and a position at a predetermined height from the ABS. The structure consists of a first pole, a recording gap layer and a second pole. The recording gap layer is made of a material having an etching rate equal to or higher than that of a material for making the first and second poles.

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Also, according to the present invention, a method of manufacturing a thin-film magnetic head includes a step of sequentially depositing a first magnetic layer, a non-magnetic layer and a second magnetic layer, and a step of forming a three-layer pole tip structure located between an ABS and a position at a predetermined height from the ABS by dry etching the first magnetic layer, the non-magnetic layer and the second magnetic layer. The non-magnetic layer is made of a material having an etching rate equal to or higher than that of a material for making the first and second magnetic layers.

The first and second pole tip elements may correspond to a lower pole tip element and an upper pole tip element, respectively, or correspond to an upper pole tip element and a lower pole tip element respectively, depending upon the layered order of each layer in the manufacturing processes of the thin-film magnetic head.

Since the recording gap layer of the conventional thin-film magnetic head is extended to an area below the coil conductor for producing recording magnetic field, it is necessary to use materials having high thermal conductivity. However, in a pole separation type recording head in which a pole tip elements are separated from a yoke portion of the recording head part, the recording gap layer does not extend to the area below the coil. Thus, various materials can be selected for making the recording gap layer without being limited to those having high thermal conductivities.

Therefore, when a three-layer pole tip structure is formed by a dry etching process such as ion milling, a recording gap layer material having an etching rate equal to or higher than that of a magnetic material for making poles is used. As a result, the shape of the three-layer pole tip structure can be easily controlled. Thus, a thin-film magnetic head can be provided by a method of easily controlling the shape of the pole tip structure without selecting the dry etching process such as ion milling, while maintaining the thermal conduction level in the coil to a conventional level.

It is preferred that the material for making the recording gap layer is one selected from a group of  $\text{SiO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{SiC}$ , and  $\text{AlN}$ .

It is also preferred that the material for making the first and second poles is nitride containing Fe.

It is further preferred that the material for making the recording gap layer is  $\text{Ta}_2\text{O}_5$ , and that the material for making the first and second poles is  $\text{NiFe}$ .

Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiments of the invention as illustrated in the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of the already described example of the conventional composite type thin-film magnetic head, perpendicular to the plane of the ABS;

FIG. 2 is a cross-sectional view of the already described another example of the conventional composite type thin-film magnetic head having the three-layer pole structure, perpendicular to the plane of the ABS;

FIG. 3 is a schematic ABS view of the example shown in FIG. 2;

FIG. 4 is a schematic ABS view of a preferred embodiment of a composite type thin-film magnetic head having an inductive recording head part and a MR reproducing head part according to the present invention;

FIG. 5 is a cross-sectional view of the magnetic head of FIG. 4, perpendicular to the plane of the ABS; and

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FIGS. 6 to 12 are schematic illustrations of a sequence of processes in the manufacturing method of the thin-film magnetic head according to the present invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 4 and 5 illustrate a preferred embodiment of a composite type thin-film magnetic head having an inductive recording head part and a MR reproducing head part according to the present invention. FIG. 4 is a schematic ABS view, and FIG. 5 is a cross-sectional view perpendicular to the plane of the ABS.

In these figures, the reference numeral 40 denotes a lower shield layer for the MR reproducing head part, 41 denotes an upper shield layer, 42 denotes a MR layer formed between the lower shield layer 40 and the upper shield layer 41 through an insulating layer 43, 44 denotes a lower pole tip element of the inductive recording head part, 45 denotes an upper pole tip element, 46 denotes a recording gap layer formed between the lower pole tip element 44 and the upper pole tip element 45, and 47 denotes a lower insulating layer deposited on the upper shield layer 41 and around a three-layer pole structure consisting of the lower pole tip element 44, the recording gap layer 46 and the upper pole tip element 45. Furthermore, in the figures, the reference numeral 48 denotes a coil conductor formed on the lower insulating layer 47, 49 denotes an upper insulating layer deposited so as to cover the coil conductor 48, and 50 denotes an upper auxiliary pole. The upper shield layer 41 contacts to the lower pole tip element 44 to act as a lower auxiliary pole. The upper auxiliary pole 50 is magnetically connected with the lower auxiliary pole (upper shield layer) 41 at its rear portion so as to constitute a magnetic yoke together with the lower auxiliary pole 41.

The recording gap layer 46 is made of a material having an etching rate equal to or higher than that of the material of the lower and upper pole tip elements 44 and 45. In this embodiment, as the magnetic material for the lower and upper pole tip elements 44 and 45, nitride of Fe series such as  $\text{FeN}$ ,  $\text{FeZrN}$  or  $\text{FeBN}$ , or a magnetic material having substantially the same etching rate as the nitride of Fe series is used. As the material of the recording gap layer 46,  $\text{AlN}$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{SiO}_2$ ,  $\text{SiC}$  or an insulating material having substantially the same etching rate as that of the aforementioned materials. However, when  $\text{NiFe}$  having a comparatively high etching rate is used as the magnetic material for the lower and upper pole tip elements 44 and 45, it is necessary to use an insulating material such as  $\text{Ta}_2\text{O}_5$  having a higher etching rate than that of  $\text{NiFe}$  for the recording gap layer 46. In stead of using an insulating material for the recording gap layer 46, a conductive non-magnetic material such as  $\text{NiP}$  can be used.

Table 1 indicates magnetic materials which can be used for the lower and upper pole tip elements 44 and 45 with their ion etching rates, and insulating materials which can be used for the recording gap layer 46 with their ion etching rates. In this Table,  $\text{Al}_2\text{O}_3$  and its ion etching rate, which has been conventionally used, is indicated as a comparative example.



TABLE 1

MATERIAL	USED FOR	ETCHING RATE (nm/min)
NiFe	MAGNETIC POLE	50
FeZrN	MAGNETIC POLE	27
Al <sub>2</sub> O <sub>3</sub>	RECORDING GAP	8.5
SiO <sub>2</sub>	RECORDING GAP	33
Ta <sub>2</sub> O <sub>5</sub>	RECORDING GAP	60
SiC	RECORDING GAP	35
AlN	RECORDING GAP	30

In the conventional head, Al<sub>2</sub>O<sub>3</sub> is used for the gap layer of the three-layer pole structure. Thus, when the three-layer pole structure is patterned by a dry etching process such as ion milling other than RIE, the side surface of the Al<sub>2</sub>O<sub>3</sub> gap layer is not easily etched due to the lower etching rate of Al<sub>2</sub>O<sub>3</sub> than that of the magnetic material of the poles. Thus, the side surfaces of the patterned recording gap layer incline with respect to that of the upper pole layer as shown in FIG. 3. In addition, the side surfaces of the lower pole layer below the recording gap layer also incline as well as the recording gap layer, thereby generating problems such as increase of recording track width and side fringing.

However, according to this embodiment, since the recording gap layer 46 is made of a material having milling rate equal to or higher than that of the magnetic material for the pole layers 44 and 45, the etching can be executed as well as a single material layer is etched. Thus, the patterning control of the shape of particularly the side surface of the three-layer pole structure is facilitated, thereby preventing the occurrence of increase of the recording track width and side fringing.

It should be noted that, in the embodiment, since the recording head part is constructed as a pole separation type in which the recording gap layer 46 is not expanded into the area below the coil 48, materials other than Al<sub>2</sub>O<sub>3</sub> can be used for the recording gap layer 46. That is, in such head, material having high thermal conductivities does not need for the recording gap layer.

FIGS. 6 to 12 are schematic ABS views illustrating processes of a method of manufacturing a thin-film magnetic head according to the present invention. The magnetic head manufactured by the following steps is a composite type thin-film magnetic head having an inductive recording head part and a MR reproducing head part.

First, on a substrate (wafer) (not shown) is formed the MR reproducing head part consisting of the lower shield layer 40, the MR layer 42, the insulating layer 43, and the upper shield layer 41. As the upper shield layer 41, about 3.5  $\mu$ m thick NiFe (82 wt % Ni-18 wt % Fe) is deposited and patterned by the photolithography technique, or formed by electroplating. After that, Al<sub>2</sub>O<sub>3</sub> insulating layer 51 is deposited on the entire surface by sputtering as shown in FIG. 6. Preferably, the thickness of the insulating layer 51 is such that the top of the upper shield 41 is fully buried therein. In the this embodiment the insulating layer has a thickness of about 8.5  $\mu$ m.

After that the insulating layer 51 is polished by a chemical-mechanical polishing (CMP) process to expose the top surface of the upper shield layer 41, as shown in FIG. 7. This CMP in this embodiment is carried out by using oxide abrasion grains with each diameter of about 0.02 to 0.3  $\mu$ m and alkaline slurry using KOH as additives. As a polishing pad, a synthetic fiber type such as urethane is used.

After completion of the CMP, on the upper shield layer 41 and the insulating layer 51, a magnetic layer 52 for the lower

pole tip element 44 of the inductive recording head part, an insulating layer for the recording gap layer 46 and a magnetic layer 54 for the upper pole tip element 45 are sequentially deposited to obtain a three-layer structure, as shown in FIG. 8.

In this embodiment, as the lower pole tip element 44, the layer 52 made of a high Bs material such as FeZrN is deposited by sputtering to have a thickness of about 0.5  $\mu$ m. As the recording gap layer 46, the insulating layer 53 made of insulating material such as SiO<sub>2</sub> is deposited by sputtering to have a thickness of about 0.3  $\mu$ m. As the upper pole tip element 45, the magnetic layer 54 made of a high Bs material such as FeZrN is deposited by sputtering to have a thickness of about 0.7  $\mu$ m.

These three layers constituting the pole tip structure can be deposited in the same chamber. For the high Bs material layers 52 and 54 made of FeZrN, a reactive DC magnetron sputtering wherein an alloy target of 88.2 at % Fe-11.8 at % Zr is sputtered under a mixed gas of Ar+N<sub>2</sub> is executed to add nitrogen to the FeZr layer. In this case, the total pressure is 0.2 Pa, and the partial pressure of nitrogen is of 10%. Also, the applied power is 1.4 kW, and the layer formation speed is 15 nm/min. For the insulating layer 53, RF magnetron sputtering wherein a SiO<sub>2</sub> target is sputtered under Ar, Ar+O<sub>2</sub>, O<sub>2</sub> gas is executed. In this case, the total pressure is 1.0 Pa, the applied power is 1.0 kW, and the layer formation speed is 4 nm/min.

Then, as shown in FIG. 8, a resist frame 55 having an opening corresponding to a portion of a mask (56 shown in FIG. 9) to be formed is formed on the magnetic layer 54 for the upper pole tip element 45. The opening has a width of about 0.3 to 2.0  $\mu$ m. In this embodiment, as the resist frame 55, a novolak type resist layer having a thickness of about 2 to 5  $\mu$ m is deposited and then patterned by a photolithography technique.

The mask 56 is then formed by electroless plating. It is desirable that before electroless plating, the wafer is immersed in 4.5% HCl solution for 1.5 min to obtain wetting properties of the plating surface.

The plated mask 56 is a metal compound composed of a base material of nickel (Ni) metal and cobalt (Co) metal, and additives of 3B group element such as boron (B) and 5B group element such as phosphorus (P). The thickness of the mask 56 is about 1.0 to 3.0  $\mu$ m.

The resist frame 55 is then removed with acetone remover thereby obtaining a structure shown in FIG. 9.

Then, the three layers 54, 53 and 52 are etched by ion milling using the mask 56. The ion milling conditions are, for example, an accelerating voltage of 500 mV and an accelerating current of 400 mA. By this ion milling, the magnetic layer 52, insulating layer 53 and magnetic layer 54 except for an area below the mask 56 are removed to form the lower pole tip element 44, recording gap layer 46 and upper pole tip element 45.

Then, the mask 56 is removed by using organic solvent such as acetone to provide a patterned three-layer pole tip structure consisting of the FeZrN lower pole tip element 44, the SiO<sub>2</sub> recording gap layer 46 and the FeZrN upper pole tip element 45, as shown in FIG. 10.

Then, as shown in FIG. 11, an insulating layer 57 consisting of an insulating material such as Al<sub>2</sub>O<sub>3</sub> or SiO<sub>2</sub> is deposited by sputtering. The thickness of the insulating layer 57 is determined to a value such that the top of the three-layer pole structure formed by ion milling is fully buried in this layer 57, for example about 0.5 to 15  $\mu$ m. In this embodiment this thickness of the insulating layer 57 is about 2.5  $\mu$ m.

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After depositing the insulating layer 57, this layer 57 is polished by a CMP process to expose the upper pole tip element 45, as shown in FIG. 12. The CMP in this embodiment is carried out using oxide abrasion grains such as  $\text{Al}_2\text{O}_3$  or  $\text{SiO}_2$ , having each diameter of about 0.02 to 0.3  $\mu\text{m}$  and alkaline slurry using KOH as additives. As a polishing pad, a synthetic fiber type such as urethane is used.

Then, on the lower insulating layer 47 is formed the coil conductor 48 on which the upper insulating layer 49 is deposited. This upper insulating layer 49 is formed by depositing a novolak type photoresist and by patterning using a photolithography technique. A resist frame is then formed by a photolithography technique and the upper auxiliary pole 50 is formed by electroplating process. The upper auxiliary pole 50 is magnetically connected to the upper shield layer 41 at the rear portion so as to form a yoke. By the above-mentioned processes, the thin-film magnetic head having the cross-sectional view of FIG. 5 can be obtained.

In stead of the mask 56, only the patterned upper pole tip element 45 is formed by plating, and then the three-layer pole structure can be formed by ion milling by using the upper pole tip element 45 as a mask.

In the above-mentioned embodiment, after forming the MR reproducing head part on the substrate, the inductive recording head part is formed. However, it is apparent that after forming the inductive recording head part on the substrate, the MR reproducing head part may be formed. In the latter case, the above-mentioned lower shield layer, the lower pole tip element, the lower auxiliary pole and the lower insulating layer will be substituted for an upper shield, an upper pole tip element, an upper auxiliary pole and an upper insulating layer, respectively.

Many widely different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not limited to the specific embodiments described in the specification, except as defined in the appended claims.

What is claimed is:

1. A thin-film magnetic head including an air bearing surface and a three-layer pole tip structure located between the air bearing surface and a position at a predetermined height from the air bearing surface, said structure consisting of a first pole, a recording gap layer and a second pole, said recording gap layer being made of a material having an etching rate equal to or higher than that of a material for making said first and second poles, the material for making said recording gap layer comprising  $\text{Ta}_2\text{O}_5$ , and the material for making said first and second poles comprising NiFe.

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2. A thin-film magnetic head comprising:  
a magnetoresistive reproducing head part;  
an inductive recording head part multilayered with said reproducing head part; and  
an air bearing surface,

said recording head part including a three-layer pole tip structure located between the air bearing surface and a position at a predetermined height from the air bearing surface, said structure consisting of a first pole, a recording gap layer and a second pole,

said recording gap layer being made of a material having an etching rate equal to or higher than that of a material for making said first and second poles, the material for making said recording gap layer comprising  $\text{Ta}_2\text{O}_5$ , and the material for making said first and second poles comprising NiFe.

3. A thin-film magnetic head including an air bearing surface and a three-layer pole tip structure located between the air bearing surface and a position at a predetermined height from the air bearing surface, said structure consisting of a first pole, a recording gap layer and a second pole, said recording gap layer being made of a material having an etching rate equal to or higher than that of a material for making said first and second poles, the material for making said first and second poles comprising a nitride containing Fe, and the material for making said recording gap layer comprising one selected from a group of  $\text{Ta}_2\text{O}_5$ , SiC, and AlN.

4. The head as claimed in claim 3, wherein the material for making said first and second poles comprises one selected from a group of FeZrN, FeBN and FeN.

5. A thin-film magnetic head comprising:  
a magnetoresistive reproducing head part;  
an inductive recording head part multilayered with said reproducing head part; and  
an air bearing surface,

said recording head part including a three-layer pole tip structure located between the air bearing surface and a position at a predetermined height from the air bearing surface, said structure consisting of a first pole, a recording gap layer and a second pole,

said recording gap layer being made of a material having an etching rate equal to or higher than that of a material for making said first and second poles, the material for making said first and second poles comprising a nitride containing Fe, and the material for making said recording gap layer comprising one selected from a group of  $\text{Ta}_2\text{O}_5$ , SiC, and AlN.

6. The head as claimed in claim 5, wherein the material for making said first and second poles comprises one selected from a group of FeZrN, FeBN and FeN.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 6,188,544 B1  
DATED : February 13, 2001  
INVENTOR(S) : Tetsuya Mino

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page.

Item [54], change "THIN-FILM MAGNETIC HEAD WITH THREE-LAYER POLE TOP STRUCTURE" to -- THIN-FILM MAGNETIC HEAD WITH THREE-LAYER POLE TIP STRUCTURE --

Signed and Sealed this

Thirteenth Day of November, 2001

Attest:

*Nicholas P. Godici*

Attesting Officer

NICHOLAS P. GODICI  
Acting Director of the United States Patent and Trademark Office